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UNITED STATES PATENT APPLICATION

FOR

METHOD AND APPARATUS FOR BENDING COMPOSITE REINFORCED PIPE

Inventor:

Norman C. Fawley

Prepared by:

BLAKELY, SOKOLOFF, TAYLOR & ZAFMAN LLP
12400 Wilshire Boulevard, 7th Floor
Los Angeles, California 90025-1030
(310) 207-3800

METHOD AND APPARATUS FOR BENDING COMPOSITE REINFORCED PIPE

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates generally to the field of composite reinforced pipe (CRP), which is used for gas and oil transmission pipelines. More particularly, the invention relates to a method and apparatus for bending CRP without cracking or delamination of the composite reinforcement.

Background

[0002] Gas and oil transmission pipelines are typically constructed with large diameter pipe buried below ground. During construction, the pipe segments must be bent to follow terrain contours. Pipe bending is typically done on site with a special-purpose bending machine. Conventional steel pipe is sufficiently ductile so that it can be bent to follow terrain contours without damaging the structural integrity of the pipe.

[0003] Composite reinforced pipe (CRP) is more difficult to bend in comparison to non-reinforced steel pipe. The composite reinforcement, which is generally a fiberglass-reinforced resin, is prone to surfacing/laminate cracking during the bending process. Such cracking allows moisture to penetrate the composite reinforcement. Unless the cracks are sealed, which can be a tedious and time-consuming process, the structural integrity of the pipe is likely to be compromised over time by the incursion of moisture. Resin cracking is more pronounced at lower temperatures and is therefore a significant problem in arctic environments.

SUMMARY OF THE INVENTION

[0004] The present invention utilizes a heater to heat Composite Reinforced Pipe (CRP) at a location where it is to be bent. The heater is placed around the CRP in line with an otherwise conventional bending machine. The composite reinforcement is heated to slightly below the heat distortion temperature (HDT) of the resin in the composite reinforcement, which allows the CRP to be bent without

cracking the resin. Resin cracking is also reduced by incorporating fibers substantially longitudinal to axis of pipe, i.e., parallel, in the composite reinforcement during manufacture of CRP and by reducing the bend per pull.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The invention is illustrated by way of example and not by way of limitation in the figures of the accompanying drawings in which like references indicate similar elements. It should be noted that references to "an" or "one" embodiment in this disclosure are not necessarily to the same embodiment, and such references mean at least one.

[0006] **Figure 1** is a schematic view of a pipe-bending apparatus implementing one embodiment of the invention.

[0007] **Figure 2** illustrates construction of a composite reinforced pipe with longitudinal reinforcing fibers.

DETAILED DESCRIPTION OF THE INVENTION

[0008] In the following description, for purposes of explanation and not limitation, specific details are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to one skilled in the art that the present invention may be practiced in other embodiments that depart from these specific details. In other instances, detailed descriptions of well-known methods and devices are omitted so as to not obscure the description of the present invention with unnecessary detail.

[0009] Referring to **Figure 1**, the present invention may be implemented in combination with a pipe-bending machine shown generally as **10**. One source of such a bending machine is CRC – Evans Pipeline International, Inc., of Tulsa, Oklahoma. A section of pipe **12** is supported by stiffback **14** and pin up shoe **16**. In a typical bending machine, stiffback **14** and pin up shoe **16** are each moveably mounted on frame **22** and are positioned by means of hydraulic cylinders **18**. A die **20** is rigidly mounted on frame **22** of bending machine **10**.

[0001] To place a bend in pipe **12**, stiffback **14** and pin up shoe **16** are elevated by hydraulic cylinders **18** until the pipe is in contact with the surface of die **20**. Additional forces are then applied through the hydraulic cylinder supporting stiffback **14** to bend pipe **12** around the curved surface of die **20**. In one

embodiment, segmented die 21 is mounted on a pipe bending machine 10 to support the underside of the pipe 12 at the bend. The segmentation allows the die to more closely follow the bend of the pipe 12. Each segment may be independently hydraulically controlled. A mandrel (not shown) is typically placed within pipe **12** and positioned at the point of contact with die **20** to support the inner wall of the pipe so that the circular cross-section of the pipe is not distorted during the bending operation. Conventional steel pipes are typically bent in increments typical one degree of bend per pipe diameter of length at several locations separated by a distance approximately equal to the diameter of the pipe until the desired angle of bend is achieved. Thus, for a 24" diameter pipe one degree of bend will be made every 24" until a desired bend is reached. In one embodiment of the invention, the frequency of bend is increased, but the degree of bend is reduced. For example, in one embodiment, a 24" diameter pipe will be bent 1/4° every 6". Thus, four bends will occur in one pipe diameter resulting in 1/4° of bend every 1/4° diameter. This is effectively a reduction in the bend per pull and correspondingly the strain within the composite reinforcement. It should be recognized that the diameter, grade of pipe, pipe wall thickness, and the yield tensile ratio of the pipe, effect the amount of bend possible. Thus, for thick walled pipe, a maximum bend may be less than 1° per pipe diameter.

[0011] The pipe is positioned longitudinally within bending machine **10** by a winch **24** and a cable **26** attached to one end of the pipe section. Alternatively, the bending machine may incorporate a system of powered rollers **50** that positions the pipe section longitudinally. Powered roller **50** permits the pipe to be moved longitudinally in either direction. An indexing wheel **62** may be provided to track the longitudinal traversal of the pipe. The indexing wheel **62** may provide input to a control unit **60**, which may include a microprocessor, an application specific integrated circuit or other processing element.

[0012] In the case of CRP, bending a section of pipe at ambient temperature is likely to produce circumferential stress cracks in the resin of the composite reinforcement on the tension side of the bend. However, such cracking generally does not occur if the resin is heated to a temperature of about its heat distortion temperature (HDT). Therefore, the present invention utilizes an induction heater **30** placed around pipe **12** at the bending machine **10**. The induction heater **30** is controlled to heat the steel core of the CRP to a temperature above the HDT of the

resin. As a result, the composite reinforcement is heated to a temperature slightly below its HDT owing to the relatively poor thermal conductivity of the composite. Once the pipe has been heated to the desired temperature, the pipe is advanced to place the heated portion directly below die **20** and the bending operation is commenced. In one embodiment, it takes four to five minutes for the composite reinforcement to reach the described temperature and the heating occurs 7′ – 10′ from the die **20**. In one embodiment, incremental bends are made at locations separated by a distance of about 1/4 of the pipe diameter (rather than the full diameter as is typical for conventional steel pipe). In experimental tests, the present invention has been successfully employed to bend 24-inch diameter CRP in ambient conditions of -20° F without cracking. In one embodiment, prior to commencing the bending operation, the CRP is preheated by introducing hot air into the pipe. This improves the efficiency of the induction heating, by in part decreasing the temperature difference between the portion of the pipe to be bent and the adjacent portions of the pipe. In one embodiment, die **20** is segmented allowing it to more closely follow the bend.

[0013] During the heating and bending process, the ends of pipe section **12** are preferably capped to prevent the flow of air through the pipe and thereby reduce heat loss to the outside environment. Simple cardboard caps are sufficient for this purpose. A small aperture can be provided in the cap to provide a pass-through for a reach rod to operate the internal mandrel.

[0014] Circumferential cracking of the composite reinforcement of CRP can also be reduced by modifying the structure of the composite reinforcement. The composite reinforcement is typically applied to the steel pipe core by winding fiberglass filaments around the pipe as it is rotated. In other embodiments, carbon fiber or other suitable fiber may be used in the composite reinforced. The filaments pass through a resin bath as they are wound on the pipe. Alternatively, resin preimpregnated fibers (prepreg) may be used. The circumferential orientation of the fiberglass filaments increases the hoop strength of the pipe; however, there is no longitudinal reinforcement of the resin. Hence, the resin is prone to developing circumferential cracks under stress.

[0015] **Figure 2** illustrates a modified construction of CRP to reduce the incidence of circumferential cracking. A steel pipe may be shot blasted to clean and

provide an anchor pattern to facilitate the adhesion of the composite reinforcement. A steel pipe core **40** is covered with a primer layer 41. The primed pipe is then circumferentially wrapped with a fiber-reinforced resin matrix **42** as is known. In addition, longitudinal fibers **44** are wrapped over and/or within the circumferential fiber-reinforced matrix **42**. This may be accomplished by applying a woven roving having both longitudinal (weft) fibers **44** and circumferential (warp) fibers **46**. A suitable woven roving for this application is 80% weft / 20% warp. Woven roving with 50% weft/50% warp could also be used. Alternatively, a indirectional weft fabric, a ± 90° stitched fabric or a ± 45° stitched fabric may be used. The weft fibers provide longitudinal reinforcement of the resin and thereby significantly reduce the incidence of circumferential cracking. In one embodiment, the fabrics barber poled onto the pipe such that in practice the weft fibers are at an angle of about 45° to the longitudinal axis of the pipe. In such embodiment, use of ± 45° fabric resulting in truly longitudinal fibers. The angle of application also depends on roll width.

[0016] As explained above, cracking of the composite reinforcement of a CRP during bending is reduced or eliminated by heating the resin. Resin elongation increases with temperature. It has been found that an elongation factor of about 20% is required to successfully bend CRP 1% per pipe diameter without inducing cracks in the resin. The amount by which the temperature of the resin must be elevated to achieve 20% elongation is, of course, influenced by the ambient temperature as well as the characteristics of the resin. Thus, it is desirable to match the resin characteristics to the environment in which the CRP is to be installed and used. Specifically, the resin should be selected to have a heat distortion temperature appropriate for the environment, e.g., arctic or tropical.

[0017] Table 1 shows resins suitable for arctic, temperate an high temperature environments:

Ambient Temp Range (°F)	Resin	PSI	HDT	Elongation
-20° - 60°	1333	2500	100°F	30%
60° - 100°	737	8000	176°F	4%
100° - 150°	701	10,000	224°F	2.5%

TABLE 1

[0018] All of these resins are commercially available from AOC Corporation of Collierville, Tennessee. As reflected in the table, there is an inverse correlation between modular strength and elongated and a positive correlation between HDT and modular strength. While these three resins are suitable for the ambient temperature ranges indicated, other resins and more granular ranges are within the scope and contemplation of the invention.

[0019] In the foregoing specification, the invention has been described with reference to specific embodiments thereof. It will, however be evident that various modifications and changes can be made thereto without departing from the broader spirit and scope of the invention as set forth in the appended claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.